The Grayscale/Spatial Resolution Trade-off and its Impact on Display System Design

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Abstract

We examine technology trade-offs related to the grayscale/spatial resolution trade-off for AMLCD-based display systems. We present new empirical results from our study of the human grayscale/spatial resolution trade-off.

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Introduction

Efficient display system design requires balancing of design factors to achieve the best performance at a low cost. The technologies used in display systems have implicit trade-offs in the cost and ease of manufacture. Which trade-offs are effective is constrained by the visual system of the user. The ultimate criterion for judging display quality resides in the human visual system, so technology trade-offs should be judged in terms of their impact on system performance with the human viewer as an essential system component. Also, there cannot be a single ergonomics-based criterion for display performance, because fully adequate performance is always task specific (for example, good entertainment display systems are often not adequate for office automation or desktop computing applications.)

We will examine technology trade-offs related to the grayscale/spatial resolution trade-off for AMLCD-based display systems used in laptop and desktop computing applications. Some of the details of the grayscale/spatial resolution trade-off have been examined by us in two papers earlier this year [1,2]. This work and empirical extensions at higher resolutions will be discussed in terms of device parameters such as pixel pitch, LC viewing angle performance, TFT performance uniformity, driver complexity, frame store depth, and controller requirements.

Spatial Resolution

Device manufacturers typically specify resolution in terms of dots per inch (dpi). This measure maps directly into manufacturing cost considerations. The resolution of a typical laptop computer display is often given in terms of pixel counts, for example, 640X480 pixels (VGA). The appropriate measure of resolution for the human visual system, however, is pixels per degree visual angle, or more specifically cycles per degree visual angle of a one-dimensional grating. There is a limiting resolution of the human visual system which is generally taken to be around 60 cycles per degree, or 120 pixels per degree, at 100% contrast for the average person. For a display viewed at 0.5 m, this would be about 350 dpi. Laptop computer displays are limited in diagonal measure (approximately 0.2 to 0.3 m) and are viewed at a distance of approximately 0.5 meters. A 30 cm diagonal VGA display (about 68 dpi) viewed at 0.5m would measure approximately 24 pixels per degree or the equivalent of 12 cycles per degree.

Some of the manufacturing factors that are controlled by these dimensions in an AMLCD are: (1) pixel aperture, (2) lithographic feature size or "design rule", (3) liquid crystal domain size, and (4) manufacturing yield. These factors are not independent. As the pixel size decreases the aperture decreases. This affects the relative size of the design rule, since TFT and storage capacitor features are usually fixed in size. As the design rule is reduced in size to accommodate higher pixel counts with reasonable aperture ratios, manufacturing yields are reduced. Finally, small aperture pixels (i.e. below 50 μm) in a TN LC design result in electric field effects which can reduce LC performance. By comparison, in high quality printing dot size or pixel counts can be as high as 1 to 3 thousand per inch (400 to 1200 per cm) to achieve grayscale through halftoning.

Grayscale

In printing grayscale is achieved by halftoning. Here very small dots of ink are used in a spatial pattern to achieve larger areas of gray out of composites of many dots of ink. In a TN LC device, grayscale can be achieved by varying the electric field on the pixel. But this has several problems. First, carefully controlling the voltage at each pixel location in an AMLCD requires a high degree of uniformity in the TFT operating characteristics. It is typically difficult to achieve uniform drive voltages in a-Si TFT AMLCDs. These problems imply greater manufacturing consistency which means lower yields and higher costs. A second problem is driver technologies. Drivers that can produce more voltage levels are more costly and require more inputs to the driver circuitry. Finally, grayscale at the pixel level requires more bit planes within the frame store which adds to the cost and complexity of the system.

Another cost of achieving grayscale by varying the transmission characteristics of the LC light valve is viewing angle. Because the light gating mechanism is the birefringence of the liquid crystal, voltages that put the LC molecule into a molecular orientation that is not homeotropic or completely relaxed into a helix result in highly anisotrophic angular light transmission. This problem has been addressed in several ways including multidomain schemes where many LC orientations are mixed to achieve more isotrophic viewing angle performance. These methods, however, can have an additional cost in terms of loss of contrast and always are more complex to manufacture.

For these reasons, many manufacturers have attempted to achieve grayscale in AMLCDs by techniques similar to halftoning in printing. These techniques use groups of pixels whose aggregate values are controlled spatially and temporally by a special controller chip which produces a dither pattern. This method relaxes the high manufacturing costs of mentioned above, but requires an expensive controller chip to be placed between the frame store and the LCD drivers.

Human Visual System

The human visual system is limited in its ability to perceive grayscale steps and spatial resolution. There is a trade-off within the visual system where one of these can be traded for the other. This is why halftoning works in printing and anti-aliasing works for lower-resolution displays. Specifying the regions of trade-off, therefore, will be useful to the display system designer who must trade cost of manufacture against system performance to achieve an efficient design. We will complete the discussion of this paper by relating our past and new empirical results from our study of the human grayscale/spatial resolution trade-off to the issues mentioned above in AMLCDs.

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